Prepared in cooperation with the Federal Emergency Management Agency

Tropical Storm Irene Flood of August 2011 in Northwestern Massachusetts

Scientific Investigations Report 2016–5027

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Upper left: Geostationary Operational Environmental Satellite (GOES) East image of Hurricane Irene making landfall near New York City on August 28, 2011. Image is courtesy of the National Oceanic and Atmospheric Administration, 2011. Lower right: Deerfield River at the Bridge Street bridge (left) and the Bridge of Flowers (right) at Shelburne Falls, Massachusetts, taken on August 28, 2011, during flood flows from tropical storm Irene. Photograph by John E. Robison, Amherst, Massachusetts.

Back cover. Maxam Road bridge on the West Branch North River in Colrain, Massachusetts, with the bridge structure at the right edge of the water (looking downstream) washed out on August 28, 2011, by tropical storm Irene. Photograph by Andrew Waite, USGS, taken on September 22, 2011.

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SALLY JEWELL, Secretary

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile per hour (mi/hr)	1.609	kilometer per hour (km/hr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

AEP	annual exceedance probability
EMA	expected moments algorithm
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIS	flood insurance study
HEC–RAS	Hydrologic Engineering Center–River Analysis System
HWM	high-water mark
MassDOT	Massachusetts Department of Transportation
NOAA	National Oceanic and Atmospheric Administration
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Tropical Storm Irene Flood of August 2011 in Northwestern Massachusetts

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Abstract

A Presidential disaster was declared in northwestern Massachusetts, following flooding from tropical storm Irene on August 28, 2011. During the storm, 3 to 10 inches of rain fell on soils that were susceptible to flash flooding because of wet antecedent conditions. The gage height at one U.S. Geological Survey streamgage rose nearly 20 feet in less than 4 hours because of the combination of saturated soils and intense rainfall. On August 28, 2011, in the Deerfield and Hoosic River Basins in northwestern Massachusetts, new peaks of record were set at six of eight U.S. Geological Survey long-term streamgages with 46 to 100 years of record. Additionally, high-water marks were surveyed and indirect measurements of peak discharge were calculated at two discontinued streamgages in the Deerfield and Hoosic River Basins with 24 and 61 years of record, respectively. This data resulted in new historic peaks of record at the two discontinued streamgages from tropical storm Irene.

Peak flows that resulted from tropical storm Irene (August 28, 2011) were determined at the U.S. Geological Survey streamgages by using stage-discharge rating curves and indirect computation methods. For six streamgages, indirect computation methods were used to compute the peak flows. Peak flows from tropical storm Irene had annual exceedance probabilities (AEPs) that ranged from 5.4 percent to less than 0.2 percent at 10 streamgages in northwestern Massachusetts.

Discharges calculated for select AEPs as a part of this study were compared with discharges published for the same AEPs in the effective Federal Emergency Management Agency flood insurance studies (FISs) for communities in the study area. Discharges estimated for the 10-, 2-, 1-, and 0.2-percent AEPs at two streamgages on the main stem of the Deerfield River ranged from about 3 percent lower to 14 percent higher than discharges in the FISs. AEP discharges calculated for two streamgages on tributaries to the Deerfield River were 27 to 89 percent higher than the FISs. For the four streamgages in the Hoosic River Basin, the 10-, 2-, 1-, and 0.2-percent AEP discharges calculated ranged from about 33 percent lower to 5 percent higher than the FISs.

The simulated 1-percent AEP discharge water-surface elevations (nonregulatory) from recent (2015–16) hydraulic models for river reaches in the study area, which include the Deerfield, Green, and North Rivers in the Deerfield River Basin and the Hoosic River in the Hoosic River Basin, were compared with water-surface profiles in the FISs. The water-surface elevation comparisons were generally done downstream and upstream from bridges, dams, and major tributaries. The simulated 1-percent AEP discharge water-surface elevations of the recent hydraulic studies averaged 2.2, 2.3, 0.3, and 0.7 ft higher than water-surface elevations in the FISs for the Deerfield, Green, North, and Hoosic Rivers, respectively. The differences in water-surface elevations between the recent (2015–16) hydraulic studies and the FISs likely are because of (1) improved land elevation data from light detection and ranging (lidar) data collected in 2012, (2) detailed surveying of hydraulic structures and cross sections throughout the river reaches in 2012–13 (reflecting structure and cross section changes during the last 30–35 years), (3) updated hydrology analyses (30–35 water years of additional peak flow data at streamgages), and (4) high-water marks from the 2011 tropical storm Irene flood being used for model calibration.

Introduction

Rainfall of 3 to 10 inches from tropical storm Irene resulted in record flooding on August 28–29, 2011, in western Massachusetts (fig. 1). On the basis of preliminary damage assessments, President Obama declared a major disaster in the Commonwealth of Massachusetts on September 3, 2011, with individual and public assistance available for Berkshire and Franklin Counties (fig. 1; Federal Emergency Management Agency, 2015). On October 20, 2011, the Presidential disaster (FEMA–4028–DR) also designated Hampden and Hampshire Counties in western Massachusetts (fig. 1; plus five other counties in eastern Massachusetts) as eligible for public assistance (Federal Emergency Management Agency, 2015). As of July 2015, Federal financial assistance to Massachusetts for recovery from tropical storm Irene totaled more than $5.5 million approved for individual assistance and more than $29.7 million obligated for public assistance (Federal Emergency Management Agency, 2015). Kinney (2011a) reported that tropical storm Irene resulted in more than

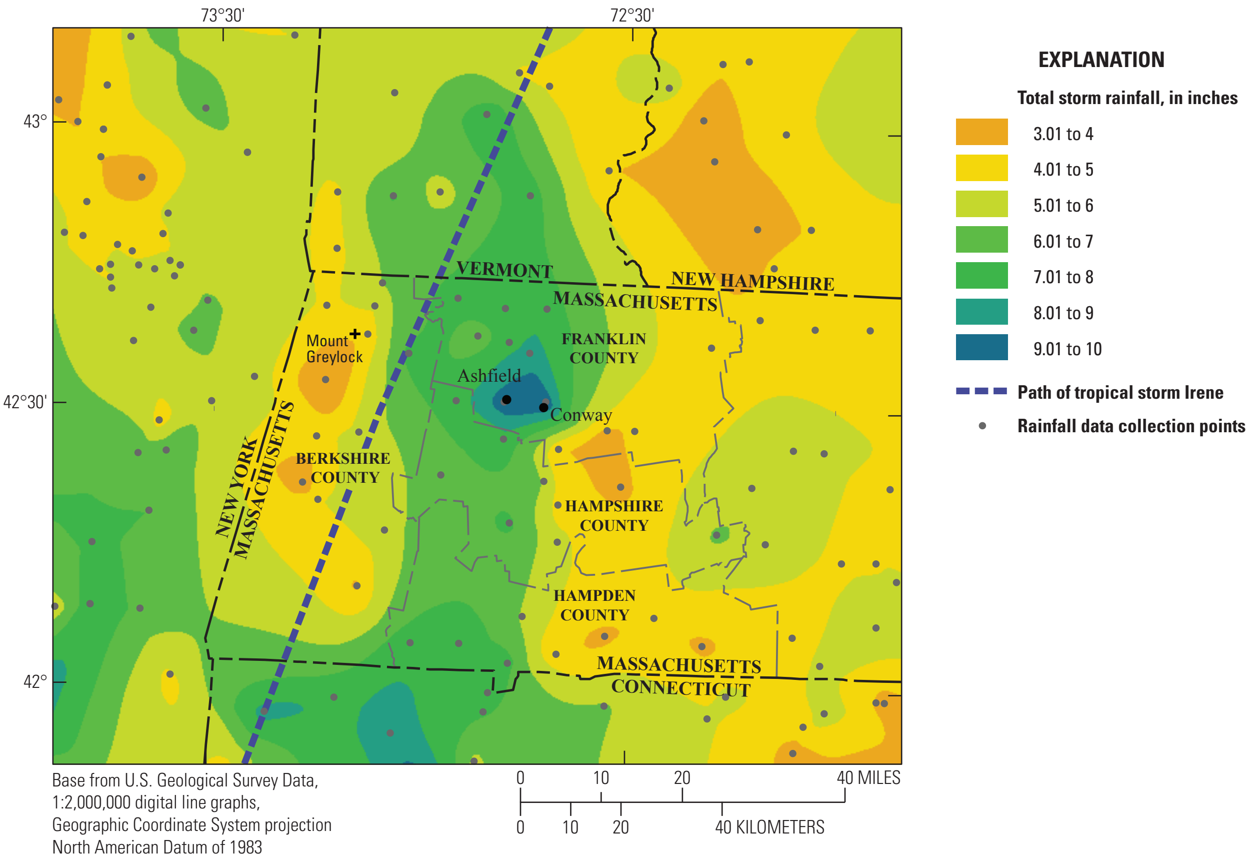


Figure 1. Distribution of rainfall and path of tropical storm Irene across western Massachusetts on August 28–29, 2011. Information on the rainfall data collection points and the path of tropical storm Irene is from the National Oceanic and Atmospheric Administration (2011) and National Weather Service (2011).

$90 million in insurance claims in western Massachusetts, including more than $750,000 in Franklin County.

The Massachusetts Department of Transportation (MassDOT) reported about $35 million in damage to bridges and roads as a result of tropical storm Irene in north Berkshire County and Franklin County in northwestern Massachusetts (Massachusetts Department of Transportation, 2011b). A 5.8-mile section of State Route 2, the primary east-west highway in northwestern Massachusetts, was one of the most visible damages from Irene, which resulted in State Route 2 being closed for more than 3 months following Irene (Massachusetts Department of Transportation, 2012a). Several sections of State Route 2 were eroded and collapsed into the Cold River, and four landslides crossed the highway (Mabee and others, 2013). Immediately following tropical storm Irene, MassDOT received $4.65 million from the Federal Highway Administration (FHWA) for emergency repairs to roads and bridges primarily in Berkshire and Franklin Counties (Massachusetts Department of Transportation, 2011a). In January 2012, MassDOT received a second grant of nearly $41 million from FHWA for damages to bridges and roads because of Irene; a large portion of the grant was for repairs to State Route 2 (Flynn, 2012; Massachusetts Department of Transportation, 2012b).

Other damages from tropical storm Irene flood flows in the Deerfield River Basin (fig. 2) were along the main stem of the Deerfield River (fig. 2) and along many of the tributaries to the Deerfield River. Numerous homes, businesses, schools, municipal infrastructure, and agricultural fields along the Deerfield River were flooded, specifically in Buckland, Charlemont, Deerfield, Greenfield, and Shelburne (fig. 2; Massachusetts Emergency Management Agency, 2011). During the height of tropical storm Irene and in some cases for several days following the storm, several bridges over the Deerfield River and roads in western Massachusetts were closed, such as the bridges over the Deerfield River on Route 8A, Route 2A, Stillwater Road, and U.S. Interstate I–91 (Abel, 2011; Johnson, 2011; Kinney, 2011b; Republican Newsroom, The, 2011; Schworm and Lutz, 2011). A building (a quilt store in Buckland) along the Deerfield River was washed away from its foundation and was deposited downstream less than 100 feet (ft; Barry, 2011). In the town

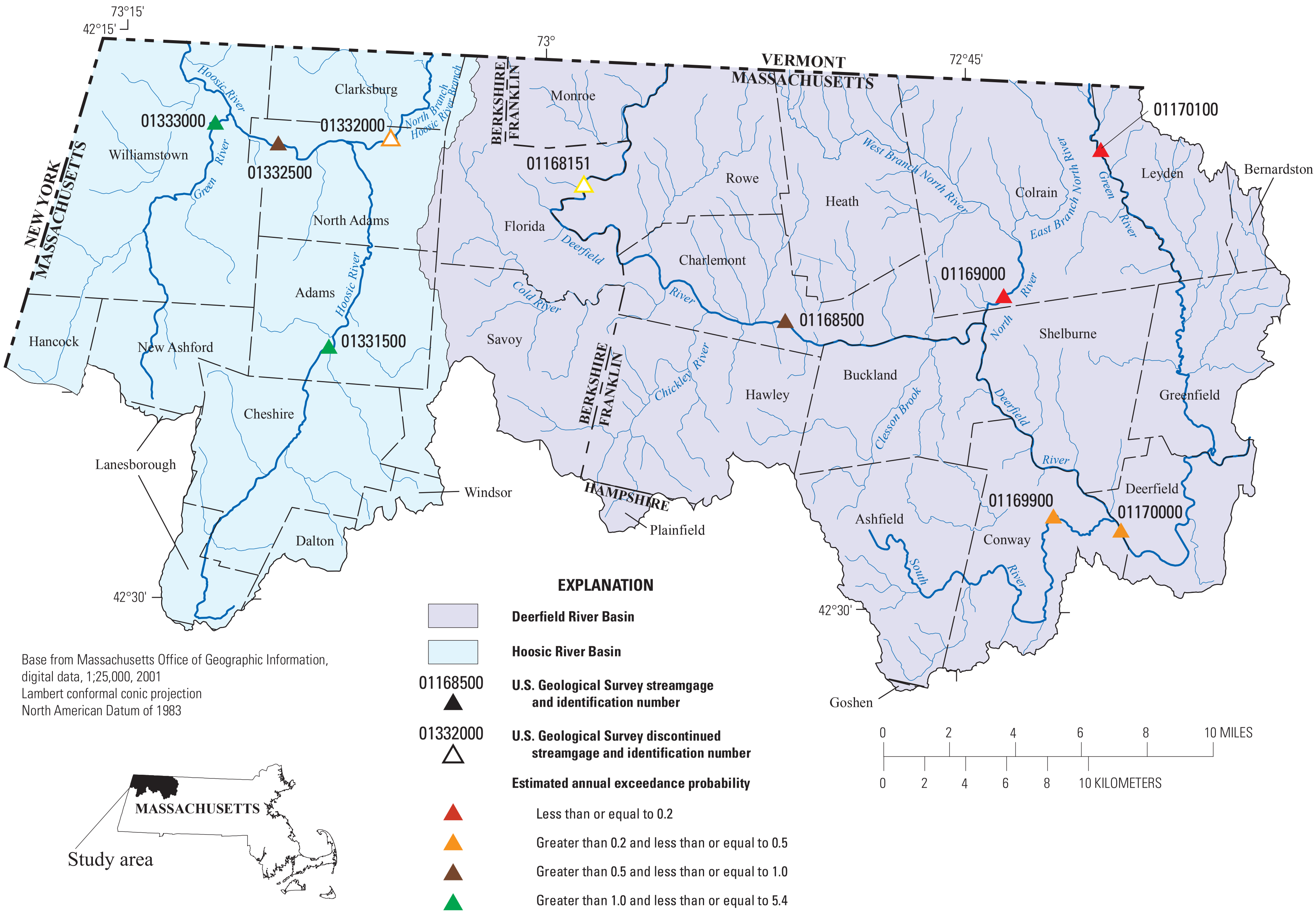


Figure 2. Location of the study area and the estimated annual exceedance probability of the August 28, 2011, tropical storm Irene peak flows at U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins in northwestern Massachusetts.

of Deerfield, damages were reported in the village of Old Deerfield, at the Deerfield Academy, at the Bement School, to municipal infrastructure, and to farm fields because of flooding from the Deerfield River (Gilmore and others, 2011).

The town of Greenfield estimated damages of $11 million, mainly to the infrastructure (Stabile, 2011). The Greenfield wastewater treatment plant on the Green River, near the confluence of the Green River with the Deerfield River, was inundated by flood waters, resulting in a shutdown and untreated wastewater discharging to the Deerfield River and Connecticut River (at the mouth of Deerfield River, not shown on fig. 2; Graham, 2011). Other damaged infrastructure along the Green River in Greenfield included the washout of Eunice Williams Road at a historic covered bridge, which was caused by the upstream failure of a segment of the dam for the Greenfield Water Supply Pumping Station. The Green River Swimming and Recreation Area in Greenfield had extensive damage because of flooding. Several private homes and businesses along the Green River also were damaged. For example, a private home was destroyed just upstream from West Leyden Road on the Colrain and Leyden (fig. 2) town border, a business on the downstream side of Colrain Road in Greenfield was flooded, and the first floor of the Museum of Our Industrial Heritage, on the downstream side of Mill Street/River Street in Greenfield, was flooded.

The well field of the village of Shelburne Falls within the town of Shelburne along the North River (fig. 2) in the midsection of the study reach in Colrain was inundated during tropical storm Irene (Murphy, 2013). The Barnhardt Manufacturing Company building along the North River in Colrain was flooded, and the Barnhardt dam (not shown), just downstream from the confluence of the East Branch North River and West Branch North River (fig. 2), was breached. On the East Branch North River in the town of Colrain, a streambank slope was eroded near the salt barn, and the highway garage and basement were flooded (Murphy, 2013). On the West Branch North River in Colrain, the Maxam Road bridge was partially washed out.

Damages from tropical storm Irene flood flows in the Hoosic River Basin primarily were on the North Branch Hoosic River and downstream from the U.S. Geological Survey (USGS) Hoosic River near Williamstown, Massachusetts, streamgage (01332500; fig. 2). The Spruces Mobile Home Park, 1 mile downstream from the streamgage, was severely affected by the flooding; two-thirds of the 226 mobile homes were damaged or destroyed (Andy McKeever, iBerkshire, written commun., 2011; Tammy Daniels, iBerkshire, written commun., 2013). The town of Williamstown (fig. 2) received a $6.13 million Federal Emergency Management Agency (FEMA) hazard mitigation grant to relocate the remaining residents of the Spruces Mobile Home Park, and a notice of discontinuance was signed by the town in February 2014 stating that the mobile home park will close February 29, 2016 (Edward Damon, Berkshire Eagle, written commun., 2013).

Other roads, bridges, private homes, and businesses were damaged from flood waters on smaller tributaries in the Deerfield and Hoosic River Basins in northwestern Massachusetts. Several of the damages were along Clesson Brook, Cold River, and South River (fig. 2); several other damages were reported that are not presented in this study.

In response to the Presidential disaster declaration for Massachusetts resulting from tropical storm Irene (DR–4028), a FEMA mission assignment was authorized for the USGS to identify and flag high-water marks (HWMs) in western Massachusetts, specifically along river reaches in the Deerfield and Hoosic River Basins and to survey their elevations. In April 2012, an interagency agreement between FEMA Region I (New England) and USGS authorized the following specific tasks: surveying of HWM elevations to the North American Vertical Datum of 1988 (NAVD 88) for selected river reaches, collecting and processing light detection and ranging (lidar) elevation data, comparing data in the effective FEMA flood insurance studies (FISs; the effective FEMA FISs are hereafter referred to as the FISs) from the late 1970s and early 1980s to data updated through 2011, producing hydraulic models for selected river reaches, and generating flood-inundation and recovery maps for selected river reaches in western Massachusetts as a result of tropical storm Irene. The HWM elevation data that were collected following the tropical storm Irene flooding on selected rivers in the study area were published by Bent and others (2013). The lidar data collected for this study are available as digital elevation model (DEM) data through the Massachusetts Office of Geographic Information System (MassGIS) (2015), and the data accuracy and other information are available from the National Oceanic and Atmospheric Administration (2013). The flood-inundation maps for the Deerfield River, Green River, North River, and Hoosic River can be viewed on the USGS flood-inundation mapping Web site at http://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html, and the flood recovery maps are available as shapefiles with the reports (Lombard and Bent, 2015a; Flynn and others, 2016; Bent and others, 2015; and Lombard and Bent, 2015b, respectively).

Purpose and Scope

The purpose of this report is to summarize the tropical storm Irene flooding on August 28, 2011, in northwestern Massachusetts. The report evaluates the estimated 10-, 2-, 1-, and 0.2-percent annual exceedance probability (AEP) discharges at USGS streamgages and the simulated 1-percent AEP discharge water-surface elevation of hydraulic models for selected river reaches in the Deerfield and Hoosic River Basins and compares the results to the FISs' AEP discharges and water-surface elevations. This report also presents a summary of the gage heights and peak flows at USGS streamgages during tropical storm Irene and describes methods used to estimate the flood flows and the AEPs. The August 28, 2011, tropical storm Irene flood flows are also compared with selected previous historic floods in northwestern Massachusetts.

Study Area

The study area is the Deerfield and Hoosic River Basins in northwestern Massachusetts (fig. 2). Elevations in the study area range from Mount Greylock at 3,487 ft to about 120 ft above sea level at the mouth of the Deerfield River. Northwestern Massachusetts is within the Hudson-Green-Notre Dame and Taconic Highlands and the Connecticut and Vermont Valley physiographic provinces (Denny, 1982, plate 1, fig. 3) and is fairly rural with most of the population living in the river valleys of the major river basins. The land use is primarily forested with some agricultural areas generally in the river valleys. The Deerfield River has a drainage area of 665 square miles (mi^2) in Vermont and Massachusetts (347 mi^2 in Massachusetts), has multiple hydroelectric facilities, and is a popular fishing destination having native and stocked trout (Deerfield River Watershed Association, 2005). The Deerfield River flows generally eastward and discharges into the Connecticut River. The Hoosic River Basin in Massachusetts is about 240 mi^2 and sustains native wild trout (Commonwealth of Massachusetts, 2016). The Hoosic River (fig. 2) generally flows northward into Vermont and New York before discharging into the Hudson River (not shown) in New York.

Climate in the Deerfield and Hoosic River Basins is fairly uniform. In Greenfield (National Oceanic and Atmospheric Administration[NOAA] station USC00193229), the annual mean precipitation is 49.50 inches and the annual mean temperature is 47.0 degrees Fahrenheit (°F), which is based on data from 1981 to 2010 (National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2016a). In North Adams (NOAA station USW00054768), the annual mean precipitation is 46.61 inches and the annual mean temperature is 46.8 °F, based on data from 1981 to 2010 (National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2016a). In Ashfield (figs. 1, 2; NOAA station USC00190213), the annual mean precipitation is 51.73 inches and the annual mean temperature is 44.0 °F, which is based on data from 1981 to 2010 (National Oceanic and Atmospheric Administration, National Centers for Environmental Information, 2016a).

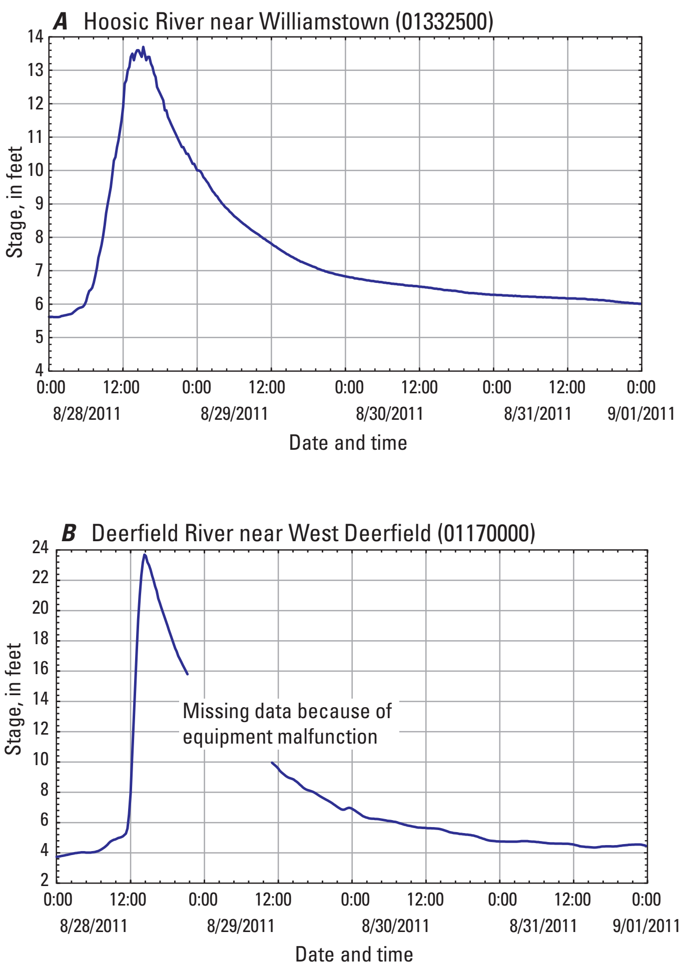


Figure 3. A rapid rise in gage height (stage) because of runoff from tropical storm Irene, August 28, 2011, for U.S. Geological Survey streamgages *A*, Hoosic River near Williamstown, Massachusetts (01332500), and *B*, Deerfield River near West Deerfield, Mass. (01170000).

Tropical Storm Irene

Irene began as a tropical storm on August 21, 2011, about 140 miles east of Martinique in the Caribbean (not shown), and passed over the island of St. Croix (not shown) that same day (Avila and Cangialosi, 2011, p. 1–3, fig. 1). As tropical storm Irene moved west-northwest and passed over eastern Puerto Rico (not shown) on August 22, 2011, the storm became a hurricane. Hurricane Irene then moved northwest, and on August 24, 2011, Irene became a category 3 hurricane. As Hurricane Irene moved about 200–300 miles offshore of Florida (not shown) on August 25, Irene turned northward up the coastline of the United States. On August 27, 2011, Hurricane Irene made landfall near Cape Lookout, North Carolina (not shown), as a category 1 hurricane and then moved back out to sea just southeast of Norfolk, Virginia (not shown), continuing northward as the hurricane skirted the Delmarva peninsula (not shown) (Fanelli and Fanelli, 2011, p. 2, figs. 1, 2*A*, *C*, and *D*). On the morning of August 28, 2011, Hurricane Irene made landfall a second time near Little Egg Inlet, New Jersey (not shown). Hurricane Irene quickly weakened and was downgraded to a tropical storm before moving briefly back out to sea near Sandy Hook, N.J., (not shown) and then making landfall a final time late in the morning of August 28 at Coney Island in Brooklyn, New York (not shown). Tropical storm Irene continued moving north-northeastward across western Connecticut and Massachusetts (fig. 1) and along the New Hampshire-Vermont border and up into northwestern Maine (not shown; Fanelli and Fanelli, 2011, p. 1, figs. 1 and 2*C*).

Irene caused damages from rainfall, wind damage, and storm surge along the east coast of the United States and in the Caribbean. Along the east coast of the United States from North Carolina to Maine, rainfall amounts ranged from less than 3 inches to almost 16 inches (Avila and Cangialosi, 2011). This area includes the noncoastal States of Pennsylvania (not shown) and Vermont, which had areas with at least 5 inches of rainfall. Maximum sustained wind speeds from South Carolina to Massachusetts ranged from about 40 to 80 miles per hour, with the highest along the North Carolina coast (Fanelli and Fanelli, 2011, tables 2*A*–*C*). Storm surge along the coast from Florida to Maine generally ranged from about 1 to 7 ft at tidal gages and temporary storm tide sensors (Fanelli and Fanelli, 2011, tables 3*A*–*C*; McCallum and others, 2012).

Rainfall totals in northwestern Massachusetts ranged from about 3 to 10 inches (fig. 1). The highest observed rainfall totals from Irene in western Massachusetts were 9.92 inches in Conway and 9.75 inches in Ashfield (National Weather Service, 2011). The NOAA, National Centers for Environmental Information (2016b) ranked August 2011 as the second wettest August in 117 years of precipitation records for Massachusetts. Rainfall in western Massachusetts during August 2011 was 11.21 inches, more than three times higher than the average August rainfall (3.41 inches; Massachusetts Department of Conservation and Recreation, 2011). During August 2011, before the arrival of tropical storm Irene, western Massachusetts had saturated soils from abundant rainfall, resulting in conditions susceptible to flash flooding (Lubchenco and Furgione, 2012).

Description of Flood

In the Deerfield and Hoosic River Basins, new record peak flows were recorded at 8 of 10 long-term (24 or more years of record) USGS streamgages in northwestern Massachusetts on August 28, 2011, from tropical storm Irene (fig. 2, table 1). Of the 10 streamgages, eight had new record peak gage heights. The Hoosic River near Williamstown, Mass., streamgage (01332500) had a new peak flow; however, the gage height was not a new peak of record because the streamgage was relocated and the gage datum was changed in 1979. The Deerfield River near Rowe, Mass., and the North Branch Hoosic River at North Adams, Mass., streamgages (01168151 and 01332000, respectively; fig. 2; table 2) were discontinued at the time of tropical storm Irene; thus, the gage heights were estimated from HWMs, and the peak flow was estimated through indirect computation of discharge.

Most of the USGS streamgages reached peak gage heights within about 20 hours of the start of the rainfall (table 1), similarly to the Hoosic River near Williamstown, Mass., streamgage (01332500; fig. 3*A*). Some streamgages reached a peak gage height in about 9–18 hours; for example, the gage height at the Deerfield River near West Deerfield, Mass., streamgage (0117000) increased from about 5 ft to nearly 24 ft in less than 4 hours (fig. 3*B*). This rapid response resulted from wet antecedent soil conditions (Lubchenco and Furgione, 2012) and intense rainfall.

Peak Flows

Peak flows for the streamgages in northwestern Massachusetts were determined by either using the stage-discharge rating curve method or the indirect discharge measurement method. The peak flows provided herein supersede those published in Bent and others (2013), Olson and Bent (2013), Olson (2014), Suro and others (2016), and USGS annual water data reports (U.S. Geological Survey, 2012a).

Determination of Peak Flows Through Stage-Discharge Rating Curves

Typically, stage-discharge rating curves (fig. 4, table 2) are used to compute the peak flows. The rating curves are developed on the basis of discharge measurements (including indirect discharge measurements) made during a wide range in stage. These stage-discharge ratings allow for continuous determination of discharge from recorded stage values.

Determination of Peak Flows Through Indirect Computation Methods

For streamgages, peak flows occasionally have to be computed by using indirect computation methods. Indirect computation methods are commonly done because the streamgage has been inactive, the flood is extreme, the estimated peak flow is more than five times than the highest discharge measurement made, the site is inaccessible under the peak flow conditions, streamflow measuring equipment cannot function properly in the extreme flow with debris or ice, or the flow cannot be safely measured (Benson and Dalrymple, 1967). The common methods of indirect computation of streamflow are slope area, contracted width opening (bridges), and flow over dams (weirs). The slope-area computation method is documented by Dalrymple and Benson (1968), and a program graphical user interface (GUI) is available for computation (Bradley, 2012). The contracted-width opening method is documented by Matthai (1967). The dam method is documented in Hulsing (1967) and in Horton (1907). All three methods were used to determine August 2011 peak flows in northwestern Massachusetts. First, HWMs were determined for a reach of river, upstream and downstream from a bridge or from a weir near the streamgage. River cross sections and the dimensions of the bridges or dams were surveyed and documented according to techniques outlined in Benson and

Table 1. Peak flows and gage heights for the August 28, 2011, flood (tropical storm Irene) compared with historical peaks for U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins, northwestern Massachusetts.

[Locations of USGS stations shown in figure 2. USGS, U.S. Geological Survey; mi², square mile; hr, hour; ft, foot; ft³/s, cubic foot per second; MA, Massachusetts; p, present; mi, mile; --, no data or could not be determined]

USGS streamgage number	USGS streamgage name	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi²)	Period of record (water years[a])	August 28, 2011, tropical storm Irene peak: Approximate time from baseflow to peak (hr)	August 28, 2011, tropical storm Irene peak: Gage height (ft)	August 28, 2011, tropical storm Irene peak: Peak flow (ft³/s)	Historical peak: Date	Historical peak: Gage height (ft)	Historical peak: Peak flow (ft³/s)	Remarks
Deerfield River Basin												
01168151	Deerfield River near Rowe, MA	42.682583	-72.976489	254	1975–97	--	19.14[b]	38,300[c]	5/29/1984	14.73	20,900	Flow regulated since 1913 by Somerset Reservoir, since 1924 by Harriman Reservoir, since 1974 by Fife Brook Reservoir, and by several power plants upstream.
01168500	Deerfield River at Charlemont, MA	42.626000	-72.854194	361	1914–p	--	20.17[b]	54,000	9/21/1938	20.17	56,300	Flow regulated since 1913 by Somerset Reservoir, since 1924 by Harriman Reservoir, since 1974 by Fife Brook Reservoir, and by several power plants upstream.
01169000	North River at Shattuckville, MA	42.638418	-72.725092	89.0	1940–p	12	18.17[b]	30,300	10/9/2005	12.32	18,800	None
01169900	South River near Conway, MA	42.542030	-72.693702	24.1	1967–p	15	14.27[b]	9,300	10/9/2005	11.90	8,770	None
01170000	Deerfield River near West Deerfield, MA	42.535920	-72.653423	557	1941–p	18	23.77	89,500	4/5/1987	17.71	61,700	Flow regulated since 1913 by Somerset Reservoir, since 1924 by Harriman Reservoir, since 1974 by Fife Brook Reservoir, and by several power plants upstream.
01170100	Green River near Colrain, MA	42.703417	-72.670647	41.4	1968–p	9	13.97[b]	13,200	10/9/2005	9.14	6,540	None
Hoosic River Basin												
01331500	Hoosic River at Adams, MA	42.611194	-73.123992	46.7	1932–p	15	9.50[b]	2,690	9/21/1938	8.25	5,080	Flow regulated by Cheshire Reservoir 5.1 mi upstream, minimial to no affect on peak flows.
01332000	North Branch Hoosic River at North Adams, MA	42.702304	-73.093159	40.9	1928[d] and 1932–90	--	14.11[b]	13,200[c]	9/21/1938	12.05	8,950[e]	None
01332500	Hoosic River near Williamstown, MA	42.700359	-73.158994	126	1941–p	14	14.58[b]	14,900	12/31/1948	14.85	13,000	Flow regulated by Cheshire Reservoir 16 mi upstream, minimial to no affect on peak flows.
01333000	Green River at Williamstown, MA	42.708970	-73.196773	42.6	1950–p	--	6.67[b]	4,140	12/21/1973	5.68	4,060	None

[a]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.

[b]Estimated from high-water marks.

[c]Estimated.

[d]Peak flow only, and was prior to the period of continuous record.

[e]Peak flow in November 1927 (exact date unknown) was 9,980 ft³/s and was prior to the period of continuous record.

Table 2. Peak gage heights, flows, flow calculation method, and corresponding annual exceedance probabilities with confidence limits for the August 28, 2011, flood (tropical storm Irene) at streamgages in northwestern Massachusetts.

[Locations of USGS stations shown in figure 2 and described in table 1. USGS, U.S. Geological Survey; ft, foot; ft^3/s, cubic foot per second; %, percent; MA, Massachusetts; --, not applicable]

USGS streamgage number	USGS streamgage name	August 28, 2011, tropical storm Irene								
				Peak flow calculation method		Peak flow analyses				
		Peak gage height (ft)	Peak flow (ft^3/s)	Stage-discharge rating curve number used during event	Indirect computation method used	Period of record used in peak flow analyses (water years[a])	Number of water years[a] used in peak flow analyses	Estimated annual exceedance probability (%)	Lower 66.7-percent confidence limit	Upper 66.7-percent confidence limit
Deerfield River Basin										
01168151	Deerfield River near Rowe, MA	19.14[b]	38,300[c]	--	Slope area (Dalrymple and Benson, 1968)	1975–1997 and 2011	24	0.9	0.76	7.19
01168500	Deerfield River at Charlemont, MA	20.17[b]	54,000	35	--	1914–2013	100	1.0	0.73	3.20
01169000	North River at Shattuckville, MA	18.17[b]	30,300	--	Width contraction (Matthai, 1967)	1940–2013	74	0.2	0.25[d]	2.39
01169900	South River near Conway, MA	14.27[b]	9,300	--	Width contraction (Matthai, 1967)	1967–2013	47	0.5	0.39	3.74
01170000	Deerfield River near West Deerfield, MA	23.77	89,500	--	Slope area (Dalrymple and Benson, 1968)	1941–2013	73	0.5	0.25	2.42
01170100	Green River near Colrain, MA	13.97[b]	13,200	--	Average used of Slope area (Dalrymple and Benson, 1968) and width contraction (Matthai, 1967)	1968–2013	46	<0.2	0.4[d]	3.82
Hoosic River Basin										
01331500	Hoosic River at Adams, MA	9.50[b]	2,690	48	--	1932–2013	82	5.4	3.55	8.46
01332000	North Branch Hoosic River at North Adams, MA	14.11[b]	13,200[c]	--	Dams (weirs; Hulsing, 1967; Horton, 1907)	1928, 1932–1990, and 2011	61	0.4	0.30	2.89
01332500	Hoosic River near Williamstown, MA	14.58[b]	14,900	40.1	--	1941–2013	73	0.9	0.25	2.42
01333000	Green River at Williamstown, MA	6.67[b]	4,140	44	--	1950–2013	64	2.4	0.29	2.76

[a]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.

[b]Estimated from high-water marks.

[c]Estimated.

[d]Lower 66.7 percent confidence limit annual exceedance probability is slighter higher than estimated annual exceedance probability if the flood is 0.2-percent or less; this occurs if the flood is ranked as the highest discharge for the period of record, and the period of record is less than about 90 years (U.S. Geological Survey, 2012b).

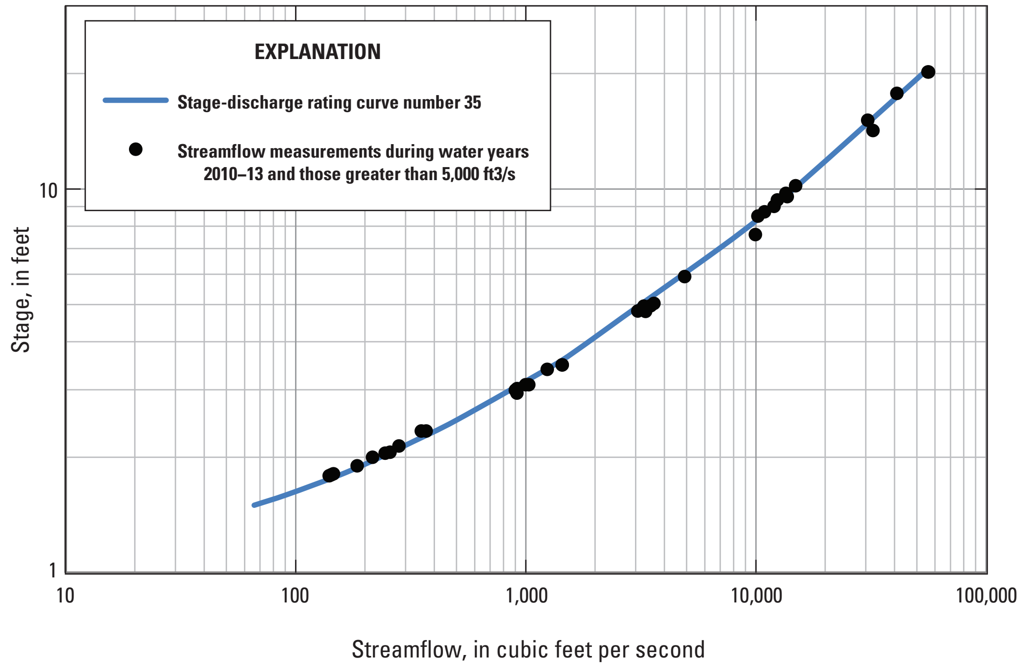


Figure 4. Stage-discharge rating curve number 35 (active during tropical storm Irene on August 28, 2011) for U.S. Geological Survey Deerfield River at Charlemont, Massachusetts, streamgage (01168500). A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.

Dalrymple (1967), Dalrymple and Benson (1968), Matthai (1967), and Hulsing (1967). Following tropical storm Irene, seven indirect measurements were done to estimate the peak flow at six streamgages (table 2). At the Green River near Colrain, Mass., streamgage (01170100), two indirect measurements were done; a slope-area computation and a contracted-width opening method. The two methods produced estimates that were within about 6 percent of each other; thus, the average of the two methods was used as the discharge for the peak. At the two discontinued streamgages, the Deerfield River near Rowe, Mass. (01168151), and the North Branch Hoosic River at North Adams, Mass. (01332000), the HWMs were considered very poor; thus, the computation of the indirect measurements was considered an estimate. At the remaining four streamgages, the peak flow was computed from the stage-discharge rating curve that was in effect for each streamgage on August 28, 2011 (table 2).

Exceedance Probabilities of Peak Flows

Peak flows for selected AEPs were calculated for the 10 streamgages in the Deerfield and Hoosic River Basins by using annual peak flow data through water year[1] 2013 available through the USGS National Water Information System Web interface (NWISWeb; U.S. Geological Survey, 2014). The eight currently (2016) operated streamgages had from 46 to 100 years of annual peak flow data, and the two discontinued streamgages had from 24 to 61 years (table 2). Calculations were made by using the expected moments algorithm (EMA; Cohn and others, 1997, 2001; Griffis and others, 2004) in the USGS PeakFQ software (Veilleux and others, 2014). For the seven streamgages with no regulations of peak flows, the AEP estimate can be improved by combining the at-site EMA estimate with a regional regression equations estimate. The two AEP estimates (at-site EMA and regional regression equation) are weighted by the inverse of the variance of each of the discharge estimates (Cohn and others, 2012). The regional regression equations used in this process were those for Vermont (Olson, 2014). The three Deerfield River streamgages near Rowe, at Charlemont, and near West Deerfield, Mass. (01168151, 01168500, and 01170000, respectively), were not weighted with the Vermont regional regression equations (Olson, 2014) because the peak flows are likely affected by streamflow regulation (dams on the river). The AEPs estimated at the three Deerfield River streamgages are based only on the EMA analyses. The estimated AEPs and associated lower and upper 66.7-percent confidence limits for the August 28, 2011, flood are listed in table 2 for the 10 streamgages in the Deerfield and Hoosic River Basins.

Along the main stem of the Deerfield River (fig. 2), the tropical storm Irene (August 28, 2011) peak flows at the three

[1]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.

streamgages had fairly similar AEPs that ranged from about 1 to 0.5 percent (table 2). For the three streamgages on the Green, North, and South Rivers (tributaries to the Deerfield River; fig. 2), the Irene peak flows had AEPs that ranged from about 0.5 to less than a 0.2 percent (table 2). The area where the Green, North, and South River Basins are located is generally where the higher rainfall amounts from Irene occurred (figs. 1, 2).

In the Hoosic River Basin, the Irene peak flows had AEPs that ranged from about 5.4 to 0.4 percent (table 2). The North Branch Hoosic River at North Adams, Mass., streamgage (01332000) had the lowest AEP and generally drains the area of the Hoosic River Basin that had the higher rainfall (figs. 1, 2). The peak flows at the Green River at Williamstown, Mass., and the Hoosic River at Adams, Mass., streamgages (01333000 and 01331500, respectively), which flow from the south to north, had slightly higher AEPs. The higher AEPs were likely related to lower rainfall in the river basins near Mount Greylock (figs. 1, 2).

Comparison of 2011 Flood Data

The tropical storm Irene, August 28, 2011, peak flows were compared with the peak flows of the selected floods that previously affected northwestern Massachusetts. Although several floods have affected western Massachusetts, the flood of November 1927 (Kinnison, 1930), the floods of March 1936 (Massachusetts Geodetic Survey, 1936; Grover, 1937a,b), the floods of September 1938 (Massachusetts Geodetic Survey, 1939; Paulsen, 1940), the New Year flood of 1949 (U.S. Geological Survey, 1952), the flood of April 1987 (Fontaine, 1987), and the flood of October 2005 (National Weather Service, 2005a, 2005b) are a few of the largest floods that are well documented for comparison to the 2011 flood. Additionally, the estimated 10-, 2-, 1-, and 0.2-percent AEP discharges at the streamgages in northwestern Massachusetts were compared with the AEPs in the FISs. Water-surface elevations of the 1-percent AEP flood determined from hydraulic models for recent (2015–16) hydraulic studies (Bent and others, 2015; Flynn and others, 2016; Lombard and Bent, 2015a,b) were compared with the water-surface elevations in the FISs.

Previous Floods

The August 28, 2011, tropical storm Irene peak flows and corresponding AEPs were compared with the following documented historic floods at three streamgages in the Deerfield and Hoosic River Basins: the floods of November 1927, March 1936, September 1938, New Year's Day 1949, April 1987, and October 2005. The streamgages that were in operation during most of these flood events were the Deerfield River at Charlemont, Mass., the Hoosic River at Adams, Mass., and the North Branch Hoosic River at North Adams, Mass.(01168500, 01331500, and 01332000, respectively; fig. 2). For the period of record through water year 2013, the annual peak discharges for the three streamgages are shown in figure 5. The comparisons for the peak discharges for these

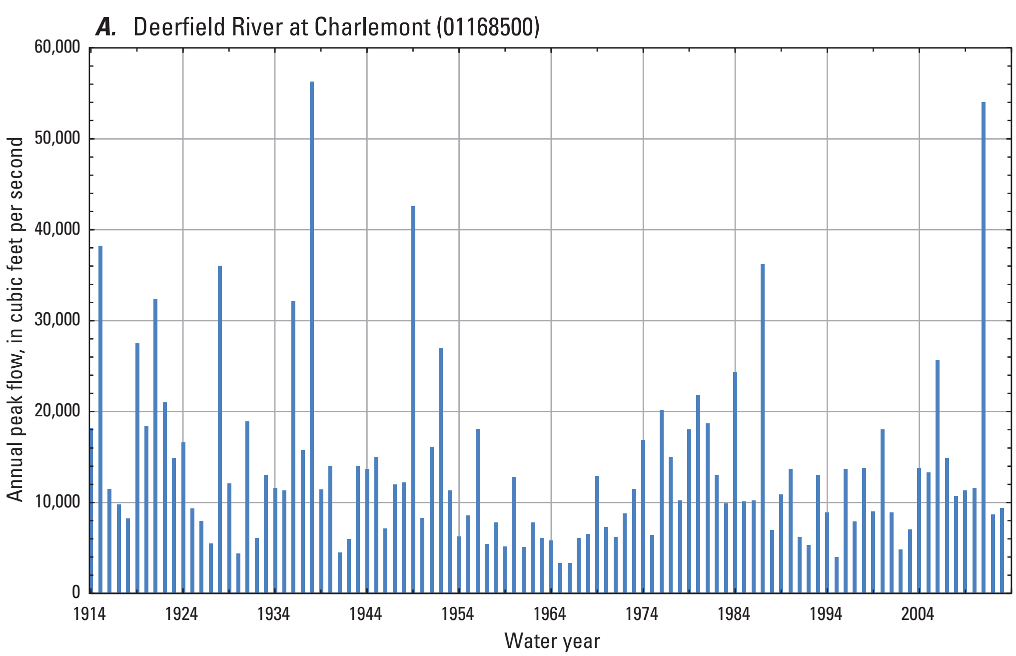
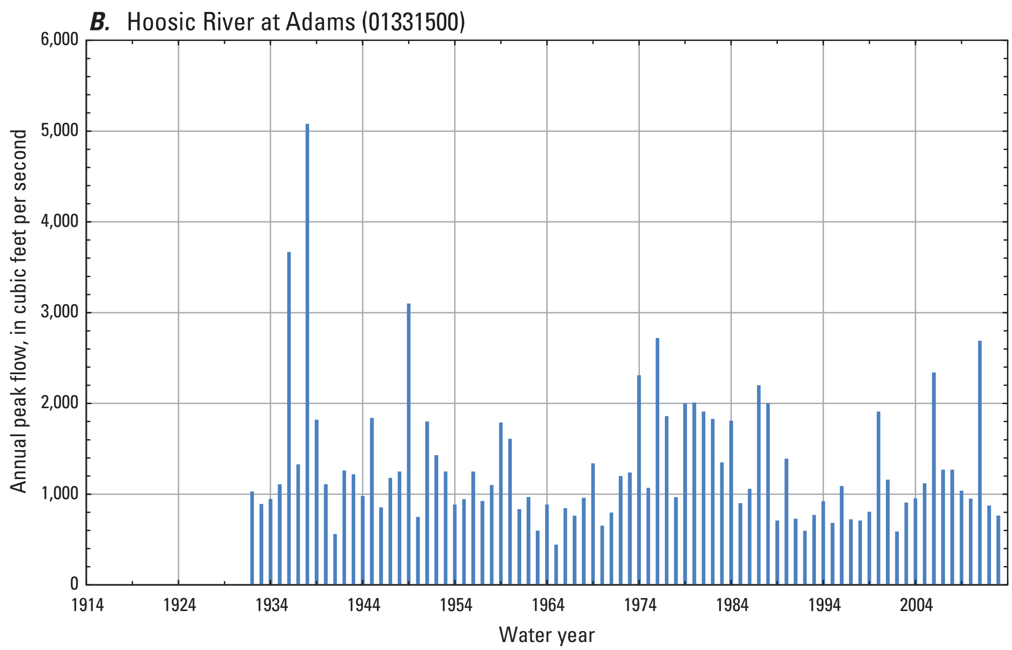


Figure 5. Annual peak flows through water year 2013 for streamgages *A*, Deerfield River at Charlemont, Massachusetts (01168500); *B*, Hoosic River at Adams, Mass. (01331500); and *C*, North Branch Hoosic River at North Adams, Mass. (01332000). A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.



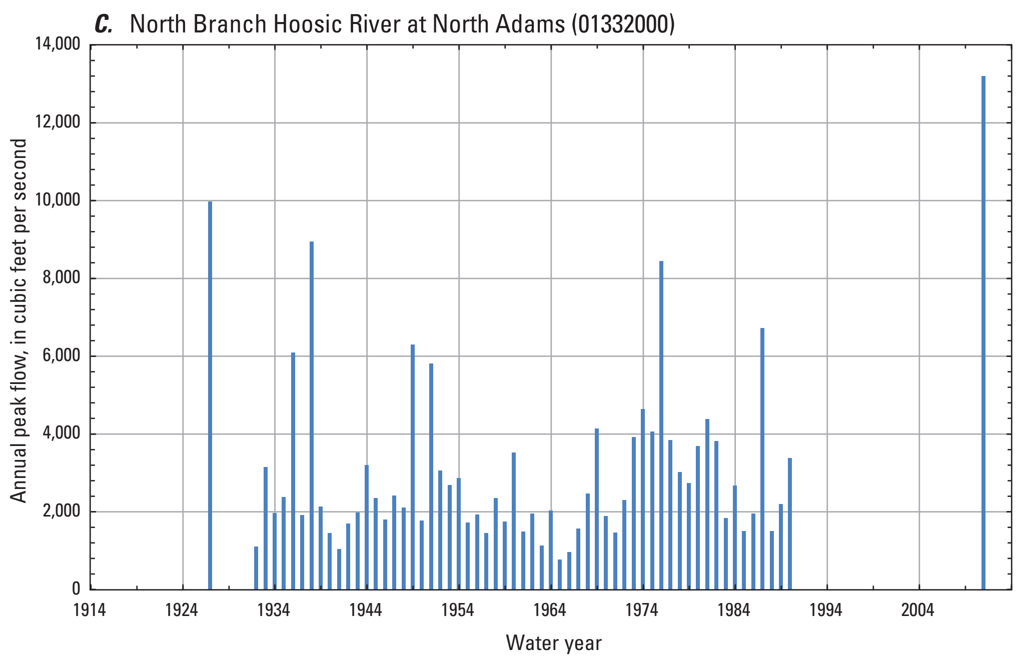


Figure 5. Annual peak flows through water year 2013 for streamgages *A*, Deerfield River at Charlemont, Massachusetts (01168500); *B*, Hoosic River at Adams, Mass. (01331500); and *C*, North Branch Hoosic River at North Adams, Mass. (01332000). A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends. —Continued

historic floods and the discharges for the 2011 flood are shown in figure 5. Other floods are noticeable for the period of record for the three streamgages; however, the floods are not well documented—such as the flood of April 1976.

The November 1927 flood flows in northwestern Massachusetts generally were on November 4 and were the result of torrential rains on November 3–4 from a tropical storm that followed heavy rains on October 18 and 21 (Kinnison, 1930). During November 2–5, 1927, rainfall data in the Deerfield and Hoosic River Basins ranged from 4 to 8 inches, most of which fell on November 3–4. This flood event was only documented at two of the three streamgages—the Deerfield River at Charlemont, Mass., and the North Branch Hoosic River at North Adams, Mass. (01168500 and 01332000, respectively; figs. 5*A* and *C*)—because the Hoosic River at Adams, Mass., streamgage (01331500) had not been established yet.

The March 1936 flood flows in northwestern Massachusetts generally were on March 18 and were the result of generally between 6 and 8 inches of rainfall during March 9–22 in addition to the existing snowpack (Grover, 1937a,b). Before the flood, on March 9, 1936, the water content of snow on the ground in this area was generally from 5 to 6 inches. Total rainfall in this area during March 9–13 was from 2 to 3 inches of rainfall and during March 16–19 was from 2 to 5 inches. The combination of existing snowpack water content and the two rainfall events in March 1936 resulted in the peak flows on March 18 at the three streamgages in northwestern Massachusetts and across much of New England (Grover, 1937a,b). The peak flows for the three streamgages for March 18, 1936, are shown in comparison to the annual peak flows for each streamgage through water year 2013 (fig. 5).

The September 1938 flood flows in northwestern Massachusetts generally were on September 21 and were the result of about 2 inches of rainfall during September 12–16 followed by 8 to 10 inches of rainfall during September 17–21 (Paulsen, 1940). This rainfall includes 24-hour rainfall totals (ending at 6 p.m.) of about 1 to 3, 2 to 3, and 4 inches on September 19, 20, and 21, respectively. The September 21 rainfall was the result of a hurricane that passed from New England in the afternoon of that day. The hurricane's center went over Hartford, Connecticut (not shown), then along the Connecticut River in Massachusetts, and then passed over the intersection of Massachusetts, New Hampshire, and Vermont before heading northwest towards Lake Champlain (not shown) (Paulsen, 1940). The peak flows for the three streamgages for September 21, 1938, are shown in comparison to the annual peak flows for each streamgage through water year 2013 (fig. 5).

The New Year flood flows of 1949 generally were on December 31, 1948, in northwestern Massachusetts (U.S. Geological Survey, 1952). The flood flows were the result of between 3 to 10 inches of rainfall, which fell from December 29, 1948, through January 1, 1949, in the Deerfield and Hoosic River Basins. The peak flows for the three streamgages for December 31, 1948, are shown in comparison to the annual peak flows for each streamgage through water year 2013 (fig. 5).

The April 1987 flood flows in northwestern Massachusetts generally were on April 4–5. The flood flows were the results of about 1 to 3 inches of rainfall on March 30 to April 2 followed by about 3–9 inches of rainfall on April 4–8 (Fontaine, 1987). Additionally, a mid-March and end-of-March snow survey in the area reported snow depths from 9 to 11 inches and no snow, respectively. Thus, the combination of snowmelt and two rain storms during about a 3-week period resulted in the early April 1987 flood. The peak flows for the three streamgages for April 4–5, 1987, are shown in comparison to the annual peak flows for each streamgage through water year 2013 (fig. 5).

The October 2005 flood flows in northwestern Massachusetts generally were on October 8–9. The flood flows were the result of about 6 to 9 inches of rainfall (National Weather Service, 2005a) from the remnants of tropical storm Tammy (National Weather Service, 2005b). The peak flows for the two streamgages for October 8–9, 2005, are shown in comparison to the annual peak flows for each streamgage through water year 2013 (figs. 5*A* and *B*). The North Branch Hoosic River at North Adams, Mass., streamgage (01332000) could not be compared with the annual peak flows through water year 2013 because the streamgage was discontinued at the time of this flood.

Published Flood Insurance Studies

Hydrology

The discharges associated with the 10-, 2-, 1-, and 0.2-percent AEPs at streamgages in the Deerfield and Hoosic River Basins and based on peak flow data through water year 2013 were compared with discharges in the FISs (table 3). The FISs for selected river reaches in the Deerfield River Basin are for the towns of Buckland (Federal Emergency Management Agency, 1979a), Charlemont (Federal Emergency Management Agency, 1980a), Colrain (Federal Emergency Management Agency, 1980b), Conway (Federal Emergency Management Agency, 1979b), Deerfield (Federal Emergency Management Agency, 1980c), Greenfield (Federal Emergency Management Agency, 1980d), and Shelburne (Federal Emergency Management Agency, 1980e) and in the Hoosic River Basin are for the city of North Adams (Federal Emergency Management Agency, 1981) and the towns of Adams (Federal Emergency Management Agency, 1983a) and Williamstown (Federal Emergency Management Agency, 1983b). The discharges computed for the AEPs at the streamgages for this study had an additional 30–35 years of peak flow data compared with the discharges in the FISs, except at the two discontinued streamgages—the Deerfield River near Rowe, Mass., and the North Branch Hoosic

Table 3. Comparison of peak flows for selected annual exceedance probabilities computed with those published in the effective Federal Emergency Management Agency flood insurance studies for U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins, northwestern Massachusetts.

[Locations of USGS stations shown in figure 2 and described in table 1. USGS, U.S. Geological Survey; ft³/s, cubic foot per second; FEMA, Federal Emergency Management Agency; FIS, Flood Insurance Study; %, percent; MA, Massachusetts; EMA, expected moments aligorithm; LPIII, log-pearson type III; mi², square miles, --, not applicable]

USGS streamgage number	Streamgage name	Source	Computation method	Computation method comments	Period of record used in computation (water years[a])	Number of water years[a] used in computation	Discharge at selected annual exceedance probability, in ft³/s				Percent difference in discharge at selected annual exceedance probability, from the effective FEMA FIS to this study (%)			
							10%	2%	1%	0.2%	10%	2%	1%	0.2%
Deerfield River Basin														
01168151	Deerfield River near Rowe, MA	Computed	EMA	Not weighted with Vermont regional regression equation (Olson, 2014).	1975–97 and 2011	24	16,400	29,500	36,500	56,900	--	--	--	--
		--	--	--	--	--	--	--	--	--				
01168500	Deerfield River at Charlemont, MA	Computed	EMA	Not weighted with Vermont regional regression equation (Olson, 2014).	1914–2013	100	25,100	44,100	54,500	85,300	6.6	3.2	1.5	-2.9
		FIS Town of Charlemont (FEMA, 1980a)	LPIII	Flows are for the Buckland and Charlemont town boundary (about 1.4 miles downstream of the streamgage) and have a drainage area of 367 mi², whereas the streamgage has a drainage area of 361 mi².	1914–77	51	23,550	42,740	53,700	87,850				
01169000	North River at Shattuckville, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1940–2013	74	10,400	17,200	20,800	30,700	28.2	27.4	27.1	77.6
		FIS Town of Colrain, MA (FEMA, 1980b)	LPIII	--	1940–76	36	8,110	13,500	16,370	17,290				
01169900	South River near Conway, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1967–2013	47	4,020	6,490	7,700	11,200	89.2	77.6	77.8	79.5
		FIS Town of Conway, MA (FEMA, 1979b)	LPIII	Flows are for the end of the detailed study reach, which is about 0.6 miles upstream of the streamgage. Drainage area is 23.2 mi² at this point on river reach, and drainage area at the streamgage is 24.1 mi².	1967–76 (10 years) at streamgage and extended back to 1940 with 36 years (1940–76) at North River at Shattuckville, MA, streamgage (01169000).	46	2,125	3,655	4,330	6,240				

Table 3. Comparison of peak flows for selected annual exceedance probabilities computed with those published in the effective Federal Emergency Management Agency flood insurance studies for U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins, northwestern Massachusetts.—Continued

[Locations of USGS stations shown in figure 2 and described in table 1. USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; FEMA, Federal Emergency Management Agency; FIS, Flood Insurance Study; %, percent; MA, Massachusetts; EMA, expected moments aligorithm; LPIII, log-pearson type III; mi^2, square miles, --, not applicable]

USGS streamgage number	Streamgage name	Source	Computation method	Computation method comments	Period of record used in computation (water years[a])	Number of water years[a] used in computation	Discharge at selected annual exceedance probability, in ft^3/s				Percent difference in discharge at selected annual exceedance probability, from the effective FEMA FIS to this study (%)			
							10%	2%	1%	0.2%	10%	2%	1%	0.2%
Deerfield River Basin—Continued														
01170000	Deerfield River near West Deerfield, MA	Computed	EMA	Not weighted with Vermont regional regression equation (Olson, 2014).	1941–2013	73	33,500	58,600	73,000	118,000	-0.6	4.2	6.9	14.1
		FIS Town of Deerfield, MA (FEMA, 1980c)	LPIII	--	1941–76 (36 years) at streamgage and extended back to 1924 with 16 years (1925–40) at Deerfield River at Charlemont, MA, streamgage (01168500).	52	33,690	56,220	68,280	103,460				
01170100	Green River near Colrain, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1968–2013	46	4,510	7,060	8,340	11,900	--	--	--	--
		--	--	--	--	--	--	--	--	--				
Hoosic River Basin														
01331500	Hoosic River at Adams, MA	Computed	EMA	--	1932–2013	82	2,170	3,480	4,170	6,110	-5.7	-14.5	-18.1	-26.6
		FIS Town of Adams, MA (FEMA, 1983a)	LPIII	--	1932–74	43	2,300	4,070	5,090	8,320				
01332000	North Branch Hoosic River at North Adams, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1928, 1932–90, and 2011	61	5,220	8,760	10,500	15,600	4.6	-5.3	-11.0	-21.6
		FIS City of North Adams, MA (FEMA, 1981)	LPIII	Flows are for the mouth of the river at the confluence with the Hoosic River (about 1.6 miles downstream of the disontinued streamgage) and have a drainage area of 41.7 mi^2, whereas the streamgage has a drainage area of 40.9 mi^2.	1928 and 1932–73	43	4,990	9,250	11,800	19,900				

Table 3. Comparison of peak flows for selected annual exceedance probabilities computed with those published in the effective Federal Emergency Management Agency flood insurance studies for U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins, northwestern Massachusetts.—Continued

[Locations of USGS stations shown in figure 2 and described in table 1. USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; FEMA, Federal Emergency Management Agency; FIS, Flood Insurance Study; %, percent; MA, Massachusetts; EMA, expected moments aligorithm; LPIII, log-pearson type III; mi^2, square miles, --, not applicable]

USGS streamgage number	Streamgage name	Source	Computation method	Computation method comments	Period of record used in computation (water years[a])	Number of water years[a] used in computation	Discharge at selected annual exceedance probability, in ft^3/s				Percent difference in discharge at selected annual exceedance probability, from the effective FEMA FIS to this study (%)			
							10%	2%	1%	0.2%	10%	2%	1%	0.2%
Hoosic River Basin—Continued														
01332500	Hoosic River near Williamstown, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1941–2013	73	7,730	12,200	14,500	20,900	-11.1	-20.8	-24.1	-31.3
		FIS Town of Williamstown, MA (FEMA, 1983b)	LPIII	Flows are from the old streamgage location about 1.4 miles downstream of the current location. The drainage area at the old location was 132 mi^2, and the current location drainage area is 126 mi^2.	1941–79	39	8,700	15,400	19,100	30,400				
01333000	Green River at Williamstown, MA	Computed	EMA	Weighted with Vermont regional regression equation (Olson, 2014).	1950–2013	62	2,770	4,290	5,040	7,090	-13.4	-22.0	-24.8	-32.5
		FIS Town of Williamstown, MA (FEMA, 1983b)	LPIII	--	1950–79	30	3,200	5,500	6,700	10,500				

[a]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the year in which it ends.

River at North Adams, Mass. (01168151 and 01332000, respectively; fig. 2).

For streamgages in the Deerfield River Basin, the computed 10-, 2-, 1-, and 0.2-percent AEP discharges generally were higher than discharges in the FISs (table 3). At the two streamgages on the main stem of the Deerfield River, the Deerfield River at Charlemont, Mass., and the Deerfield River near West Deerfield, Mass. (01168500 and 01170000, respectively; fig. 2), the computed AEP discharges had differences that ranged from about 3 percent lower to 14 percent higher than discharges in the FISs. The largest differences between the AEP discharges computed and those in the FISs in the Deerfield River Basin were at the two streamgages on tributaries to the Deerfield River, the North River at Shattuckville, Mass., and the South River near Conway, Mass. (01169000 and 01169900, respectively; fig. 2). Estimated AEP discharges at these two streamgages ranged from about 27 to 89 percent higher than the FISs.

In the Hoosic River Basin (fig. 2), the 10-, 2-, 1-, and 0.2-percent AEP discharges computed for the four streamgages ranged from about 33 percent lower to 5 percent higher than discharges in the FISs (table 3). Only the 4-percent AEP discharge at the North Branch Hoosic River at North Adams, Mass., streamgage (01332000) indicated an increase (4.6 percent); all other AEP discharges computed at the four streamgages decreased compared with discharges in the FISs (table 3).

The most likely reason for the percent differences between the 10-, 2-, 1-, and 0.2-percent AEP discharges seen on the tributaries to the Deerfield River and in the Hoosic River Basin is the availability of an additional 30–35 years of annual peak flows for AEP analyses. The large percent differences for the North River at Shattuckville, Mass., and the South River near Conway, Mass., streamgages (01169000 and 01169900, respectively) may be that the annual peak flows for the streamgages indicated a significant (p-value less than or equal to 0.05) positive trend over their period of record. The other streamgages in the study area did not indicate a significant positive or negative trend in annual peak flows over their period of record. The percent differences also could be related to land-use changes—such as any increases in greater area of urban land uses because of increased medium- to high-density areas of residential housing, commercial and industrial development, and roads and highways in the river basins.

Water-Surface Elevations

The water-surface elevations of the 1-percent AEP discharge were simulated from hydraulic models for sections of the Deerfield River (Lombard and Bent, 2015b), Green River (Flynn and others, 2016), North River (Bent and others, 2015), and Hoosic River (Lombard and Bent, 2015a). The hydraulic modeling for these studies was completed using the U.S. Army Corps of Engineer (USACE) Hydrologic Engineering Center–River Analysis System (HEC–RAS) model. The simulated water-surface elevations of the 1-percent AEP discharge from these recent (2015–16) studies were compared with those published in the FISs at select locations in the coinciding river reaches. The simulated water-surface elevations of the 1-percent AEP discharge from these recent studies is nonregulatory and does not supersede those in the published FISs. The FIS water-surface elevations were converted from National Geodetic Vertical Datum of 1929 (NGVD 29) to NAVD 88 by using the average conversion from the latitudes and longitudes of a river reach for about three to five locations depending on how much the conversion values differed along the river reach. Generally, the conversion values only differed a few hundreds of a foot along a river reach. The conversion values were determined by using the National Geodetic Survey VERTCON (orthometric height conversion program; http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl; Gilbert, 1999). If the location distances for the FIS water-surface elevations were in miles, the distance was converted into feet from the starting location of the river reach, which was generally the confluence with another river.

The simulated water-surface elevations of the 1-percent AEP discharge for the Deerfield River determined from the HEC–RAS hydraulic model developed by Lombard and Bent (2015b) were compared with those in the FISs for the (1) town of Deerfield (1980c) from the confluence of the Connecticut River upstream to the town boundary with Conway, (2) town of Shelburne (1980e) from just downstream from dam number 3 upstream to State Route 2, and (3) town of Charlemont (1980a) from dam number 4 upstream to the railroad bridge just downstream from the Cold River tributary. The comparisons of the two water-surface elevations were made at 25 selected locations generally upstream and downstream from bridges, dams, and major tributaries (table 4). The simulated water-surface elevations of the 1-percent AEP discharge (Lombard and Bent, 2015b) averaged 2.2 ft higher (median 1.5 ft higher) than the water-surface elevations from the FISs. The difference between 1-percent AEP discharge water-surface elevations in Lombard and Bent (2015b) and the FISs ranged from 2.0 ft lower to 7.3 ft higher (table 4).

The simulated water-surface elevations of the 1-percent AEP discharge for the Green River determined from the HEC–RAS hydraulic model developed by Flynn and others (2016) were compared with those in the FIS for the town of Greenfield (1980d) from the confluence with the Deerfield River upstream from the town boundary between Greenfield, Colrain, and West Leyden. The water-surface elevations were compared at 23 selected locations, generally upstream and downstream from bridges, dams, and major tributaries (table 5). The simulated water-surface elevations of the 1-percent AEP discharge (Flynn and others, 2016) averaged 2.3 ft higher (median 2.4 ft higher) than the FIS water-surface elevations. The difference between 1-percent AEP discharge water-surface elevations in Flynn and others (2016) and the FIS ranged from 6.1 ft lower to 6.1 ft higher (table 5).

The simulated water-surface elevations of the 1-percent AEP discharge for the North River determined from the

Table 4. Comparison of the simulated water-surface elevations for the Deerfield River for the 1-percent annual exceedance probability discharge determined by Lombard and Bent (2015b) with those published in the effective Federal Emergency Management Agency flood insurance studies.

[Cells shaded gray indicate locations that can be affected by backwater from the Connecticut River, but the water-surface elevations presented are not backwater elevations. Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; Rt., Route; Rd., Road; USGS, U.S. Geological Survey; MA, Massachusetts; St., Street; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS towns of Deerfield (FEMA, 1980c), Shelburne (FEMA, 1980e), and Charlemont, Massachusetts (FEMA, 1980a)	Lombard and Bent (2015b) USACE HEC–RAS hydraulic model	FIS towns of Deerfield (FEMA, 1980c), Shelburne (FEMA, 1980e), and Charlemont (FEMA, 1980a)	Lombard and Bent (2015b) USACE HEC–RAS hydraulic model	Difference in FIS and Lombard and Bent (2015b) USACE HEC–RAS hydraulic model water-surface elevation (ft)[c]
	Location from confluence with Connecticut River (ft)[a]	Location from confluence with Connecticut River (ft)	Water-surface elevation–converted to NAVD 88 (ft)[b]	Water-surface elevation–NAVD 88 (ft)	
Confluence with Connecticut River	407	637	122.4	126.6	4.2
DS from railroad bridge, Deerfield and Greenfield, MA	2,344	1,618	130.7	130.8	0.1
US from railroad bridge, Deerfield and Greenfield	--	2,240	--	132.8	--
DS from railroad bridge, Deerfield and Greenfield	5,914	5,111	132.6	135.9	3.4
US from failroad bridge, Deerfield and Greenfield	--	5,737	--	138.2	--
DS from State Rt. 5 and 10, Deerfield and Greenfield	--	5,737	--	138.2	--
US from State Rt. 5 and 10, Deerfield and Greenfield	6,283	6,494	133.9	140.1	6.3
DS from U.S. Interstate I–91 Northbound, Deerfield	39,700	38,887	154.4	153.5	-0.8
US from U.S. Interstate I–91 Northbound, Deerfield	40,870	40,706	157.7	159.6	2.0
DS from Stillwater Bridge, Upper Rd., Deerfield	42,400	41,800	157.7	161.3	3.7
US from Stillwater Bridge, Upper Rd., Deerfield	43,670	42,686	161.6	168.8	7.3
USGS streamgage Deerfield River near West Deerfield, MA (01170000)	50,480	50,623	173.6	178.7	5.1
Confluence with South River	52,540	51,628	177.9	181.4	3.5
DS from Dam #3, Buckland and Shelburne, MA	--	88,700	--	360.3	--
US from Dam #3, Buckland and Shelburne	89,340	89,313	410.2	411.7	1.5
DS from steel bridge, Bridge St., Buckland and Shelburne	89,710	89,796	411.1	411.8	0.7
US from Bridge of Flowers, Buckland and Shelburne	90,290	90,699	414.7	420.6	5.9

Table 4. Comparison of the simulated water-surface elevations for the Deerfield River for the 1-percent annual exceedance probability discharge determined by Lombard and Bent (2015b) with those published in the effective Federal Emergency Management Agency flood insurance studies.—Continued

[Cells shaded gray indicate locations that can be affected by backwater from the Connecticut River, but the water-surface elevations presented are not backwater elevations. Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; Rt., Route; Rd., Road; USGS, U.S. Geological Survey; MA, Massachusetts; St., Street; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS towns of Deerfield (FEMA, 1980c), Shelburne (FEMA, 1980e), and Charlemont, Massachusetts (FEMA, 1980a)	Lombard and Bent (2015b) USACE HEC–RAS hydraulic model	FIS towns of Deerfield (FEMA, 1980c), Shelburne (FEMA, 1980e), and Charlemont (FEMA, 1980a)	Lombard and Bent (2015b) USACE HEC–RAS hydraulic model	Difference in FIS and Lombard and Bent (2015b) USACE HEC–RAS hydraulic model water-surface elevation (ft)[c]
	Location from confluence with Connecticut River (ft)[a]	Location from confluence with Connecticut River (ft)	Water-surface elevation–converted to NAVD 88 (ft)[b]	Water-surface elevation–NAVD 88 (ft)	
DS from State Rt. 2 bridge, Buckland and Shelburne	93,390	93,333	422.2	422.4	0.2
US from State Rt. 2 bridge, Buckland and Shelburne	93,500	94,300	422.9	423.6	0.7
DS from Dam #4, Buckland and Charlemont, MA	--	103,761	--	446.2	--
US from Dam #4, Buckland and Charlemont	104,020	104,499	480.0	486.0	6.0
DS from State Rt. 2 bridge, Buckland and Charlemont	104,440	104,684	481.1	486.2	5.1
US from State Rt. 2 bridge, Buckland and Charlemont	104,740	105,234	481.1	486.1	5.0
USGS streamgage Deerfield River at Charlemont, MA (01168500)	135,850	135,620	537.8	536.3	-1.5
DS from State Rt. 8A bridge, Charlemont	143,620	143,693	554.0	552.0	-2.0
US from State Rt. 8A bridge, Charlemont	143,830	144,321	554.6	553.1	-1.5
DS from State Rt. 2 Bridge, Charlemont	152,490	152,572	572.5	573.4	0.9
US from State Rt. 2 Bridge, Charlemont	152,920	153,480	573.6	575.0	1.4
DS from railroad bridge, Charlemont	157,660	158,173	593.6	591.8	-1.8
US from railroad bridge, Charlemont	157,870	158,527	597.4	596.7	-0.7
			Number of observations		25
			Minimum		-2.0
			Maximum		7.3
			Average		2.2
			Median		1.5

[a]The FIS location in miles from confluence with Connecticut River was converted to feet.

[b]The average conversion value from NGVD 29 to NAVD 88 for the FIS water-surface elevations was -0.55 ft. The conversion was done using the National Geodetic Service VERTCON orthometric height conversion program (Gilbert, 1999) at http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl.

[c]The difference may not be exact to the tenth of a foot because of rounding of FIS and hydraulic model values.

Table 5. Comparison of the water-surface elevations for the Green River for the 1-percent annual exceedance probability discharge determined by Flynn and others (2016) with those published in the effective Federal Emergency Management Agency flood insurance study.

[Cells shaded gray indicate locations that can be affected by backwater from the Deerfield and Connecticut Rivers, but the water-surface elevations presented are not backwater elevations. Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; St., Street; Rt., Route; Rd., Road; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS town of Greenfield, Massachusetts (FEMA, 1980d)	Flynn and others (2016) USACE HEC–RAS hydraulic model	FIS town of Greenfield (FEMA, 1980d)	Flynn and others (2016) USACE HEC–RAS hydraulic model	Difference in FIS and Flynn and others (2016) USACE HEC–RAS hydraulic model water-surface elevation (ft)[c]
	Location from confluence with Deerfield River (ft)[a]	Location from confluence with Deerfield River (ft)	Water-surface elevation–converted to NAVD 88 (ft)[b]	Water-surface elevation–NAVD 88 (ft)	
Confluence with Deerfield River	--	20	--	122.6	--
DS from footbridge	3,326	3,527	128.4	133.6	5.2
US from footbridge	4,435	4,389	132.1	136.8	4.7
DS from Meridian St.	--	5,864	--	138.6	--
US from Meridian St. and DS from Wiley-Russell Dam	6,019	5,986	141.8	144.9	3.1
US from Wiley-Russell Dam	6,230	6,215	143.3	145.7	2.4
DS from Mill St. and dam	7,814	7,807	146.7	148.4	1.8
US from Mill St. and dam	8,026	8,054	152.4	153.9	1.5
DS from railroad bridge	10,138	10,138	155.9	156.4	0.5
US from railroad bridge	10,243	10,326	156.2	158.4	2.2
DS from State Rt. 2A	10,454	10,438	156.4	157.9	1.5
US from State Rt. 2A	10,666	10,666	156.8	159.5	2.7
DS from Colrain St.	12,989	12,990	159.0	162.0	3.1
US from Colrain St.	13,200	13,158	162.0	163.5	1.6
DS from U.S. Interstate I–91 (Northbound)	17,424	17,725	164.6	167.0	2.4
US from U.S. Interstate I–91 (Southbound)	18,163	18,061	167.4	169.8	2.4
DS from Nash Mill Rd.	18,797	19,057	167.6	170.9	3.4
US from Nash Mill Rd.	19,114	19,219	168.0	171.0	3.0
DS from footbridge and dam	19,536	19,724	168.1	171.0	3.0
US from footbridge and dam	19,642	19,785	168.2	171.1	2.9
DS from Allen Brook	22,229	21,746	169.2	171.1	1.9
US from Allen Brook	22,334	23,678	169.3	171.4	2.1

Table 5. Comparison of the water-surface elevations for the Green River for the 1-percent annual exceedance probability discharge determined by Flynn and others (2016) with those published in the effective Federal Emergency Management Agency flood insurance study.—Continued

[Cells shaded gray indicate locations that can be affected by backwater from the Deerfield and Connecticut Rivers, but the water-surface elevations presented are not backwater elevations. Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; St., Street; Rt., Route; Rd., Road; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS town of Greenfield, Massachusetts (FEMA, 1980d)	Flynn and others (2016) USACE HEC–RAS hydraulic model	FIS town of Greenfield (FEMA, 1980d)	Flynn and others (2016) USACE HEC–RAS hydraulic model	Difference in FIS and Flynn and others (2016) USACE HEC–RAS hydraulic model water-surface elevation (ft)[c]
	Location from confluence with Deerfield River (ft)[a]	Location from confluence with Deerfield River (ft)	Water-surface elevation–converted to NAVD 88 (ft)[b]	Water-surface elevation–NAVD 88 (ft)	
DS from Hinsdale Brook	28,882	--	181.5	--	--
US from Hinsdale Brook	28,987	29,291	181.9	182.5	0.6
DS from Eunice Williams Rd. and dam	43,718	43,878	242.1	236.0	-6.1
US from Eunice Williams Rd. and dam	43,930	44,258	244.8	250.9	6.1
			Number of observations		23
			Minimum		-6.1
			Maximum		6.1
			Average		2.3
			Median		2.4

[a]The FIS location in miles from confluence with Deerfield River was converted to feet.

[b]The average conversion value from NGVD 29 to NAVD 88 for the FIS water-surface elevations was -0.54 ft. The conversion was done using the National Geodetic Service VERTCON orthometric height conversion program (Gilbert, 1999) at http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl.

[c]The difference may not be exact to the tenth of a foot because of rounding of FIS and hydraulic model values.

HEC–RAS hydraulic model developed by Bent and others (2015) were compared with those of the FIS for the town of Colrain (1980b) from the confluence with the Deerfield River upstream to the confluence of the East Branch North River and West Branch North River. The water-surface elevations were compared at seven selected locations generally at locations upstream and downstream from bridges and dams (table 6). The simulated water-surface elevations of the 1-percent AEP discharge (Bent and others, 2015) averaged 0.3 ft higher (median 1.7 ft higher) than the FIS water-surface elevations. The difference between 1-percent AEP discharge water-surface elevations in Bent and others (2015) and the FIS ranged from 7.6 ft lower to 3.7 ft higher. The 7.6 ft lower water-surface elevation (Bent and others, 2015) was upstream from Barnhardt dam (just downstream from the confluence of the East Branch North River and West Branch North River), which was breached during tropical storm Irene and currently (2016) has not been repaired. In the model of a recent study (Bent and others, 2015), the breached dam does not provide storage and, consequently, indicates that the model has a lower water-surface elevation at this location compared with the water-surface elevation in the FIS, which has the dam with no breach.

The simulated water-surface elevations of the 1-percent AEP discharge for the Hoosic River determined from the HEC–RAS hydraulic model developed by Lombard and Bent (2015a) were compared with those of the FISs for the town of Williamstown (1983b) and the city of North Adams (1981) from the Massachusetts-Vermont State border in Williamstown upstream to the confluence with the North Branch Hoosic River in the City of North Adams. The water-surface elevations were compared at 26 selected locations generally upstream and downstream from bridges, dams, and major tributaries (table 7). The simulated water-surface elevations of the 1-percent AEP discharge (Lombard and Bent, 2015a) averaged 0.7 ft higher (median 0.6 ft higher) than the FISs' water-surface elevations. The difference between 1-percent AEP discharge water-surface elevations in Lombard and Bent (2015a) and the FISs ranged from 2.7 ft lower to 7.2 ft higher (table 7).

Table 6. Comparison of the water-surface elevations for the North River for the 1-percent annual exceedance probability discharge determined by Bent and others (2015) with those published in the effective Federal Emergency Management Agency flood insurance study.

[Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; USGS, U.S. Geological Survey; MA, Massachusetts; DS, downstream; US, upstream; Rt., Route; Rd., Road; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS, town of Colrain, Massachusetts (FEMA, 1980b)	Bent and others (2015) USACE HEC–RAS hydraulic model	FIS, town of Colrain (FEMA, 1980b)	Bent and others (2015) USACE HEC–RAS hydraulic model	Difference in FIS and Bent and others (2015) USACE HEC–RAS hydraulic model water-surface elevation (ft)
	Location from confluence with Deerfield River (ft)[a]	Location from confluence with Deerfield River (ft)	Water-surface elevation converted to NAVD 88 (ft)[b]	Water-surface elevation–NAVD 88 (ft)	
USGS streamgage North River at Shattuckville, MA (01169000)	6,389	6,524	470.3	473.5	3.2
DS from State Rt. 112	13,517	13,560	501.5	501.0	-0.5
US from State Rt. 112	13,622	13,628	503.5	502.8	-0.7
DS from Adamsville Rd.	15,682	15,608	507.1	509.8	2.7
US from Adamsville Rd.	15,734	15,675	508.3	512.0	3.7
DS from Adamsville Dam	17,266	17,212	516.0	517.7	1.7
US from Adamsville Dam	17,318	17,282	525.3	517.7[c]	-7.6
			Number of observations		7
			Minimum		-7.6
			Maximum		3.7
			Average		0.3
			Median		1.7

[a]The FIS location in miles from confluence with Deerfield River was converted to feet.

[b]The average conversion value from NGVD 29 to NAVD 88 for the FIS water-surface elevations was -0.48 ft. The conversion was done using the National Geodetic Service VERTCON orthometric height conversion program (Gilbert, 1999) at http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl.

[c]Elevation of water-surface may be affected by breached section of dam due to tropical storm Irene August 28, 2011.

Table 7. Comparison of the water-surface elevations for the Hoosic River for the 1-percent annual exceedance probability discharge determined by Lombard and Bent (2015a) with those published in the effective Federal Emergency Management Agency flood insurance studies.

[Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; Rt., Route; Rd., Road; Ave., Avenue; USGS, U.S. Geological Survey; MA, Massachusetts; St., Street; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS, town of Williamstown (FEMA, 1983b) and city of North Adams, Massachusetts (FEMA, 1981)	Lombard and Bent (2015a) USACE HEC–RAS hydraulic model	FIS, town of Williamstown (FEMA, 1983b) and city of North Adams (FEMA, 1981)	Lombard and Bent (2015a) USACE HEC–RAS hydraulic model	Difference between FIS and Lombard and Bent (2015a) USACE HEC–RAS hydraulic model water-surface elevation (ft)
	Location from Massachusetts-Vermont State border (ft)	Location from Massachusetts-Vermont State border (ft)	Water-surface elevation, converted to NAVD 88 (ft)[a]	Water-surface elevation, NAVD 88 (ft)	
Massachusetts-Vermont State border	0	490	565.9	571.6	5.7
DS from Broad Brook, Williamstown	2,900	1,983	577.3	574.6	-2.7
US from Broad Brook, Williamstown	3,100	2,448	577.8	576.0	-1.8
DS from Hemlock Brook, Williamstown	7,800	7,255	583.4	583.9	0.5
US from Hemlock Brook, Williamstown	8,000	8,312	583.6	585.0	1.4
DS from State Rt. 7/Simonds Rd., Williamstown	10,400	10,216	587.0	587.0	0.0
US from State Rt. 7/Simonds Rd., Williamstown	10,600	10,614	589.7	590.6	0.9
DS from Cole Ave., Williamstown	16,900	16,586	598.3	596.5	-1.8
US from Cole Ave., Williamstown	17,050	16,942	600.7	599.1	-1.6
DS from Green River, Williamstown	19,000	18,738	604.9	603.8	-1.1
US from Green River, Williamstown	19,100	18,946	605.0	604.0	-1.0
Williamstown and North Adams town border	24,250	23,828	612.6	611.1	-1.5
DS from Ashton Ave., North Adams	26,450	25,960	617.7	616.9	-0.8
US from Ashton Ave., North Adams	26,550	26,272	617.9	619.2	1.3
DS from Barber Dam, North Adams	29,450	28,976	623.4	622.8	-0.6
US from Barber Dam, North Adams (USGS streamgage Hoosic River at Adams, MA 01332500)	29,750	29,232	628.9	630.3	1.4
DS from Protection Ave., North Adams	32,050	31,483	632.5	633.1	0.6
US from Protection Ave., North Adams	32,250	31,809	633.6	634.3	0.7
DS from State Rt. 2, North Adams	33,000	32,324	634.6	634.7	0.1
US from State Rt. 2, North Adams	33,100	32,659	634.6	635.2	0.6

Table 7. Comparison of the water-surface elevations for the Hoosic River for the 1-percent annual exceedance probability discharge determined by Lombard and Bent (2015a) with those published in the effective Federal Emergency Management Agency flood insurance studies.—Continued

[Streamgage locations shown on figure 2 and described in table 1. FIS, flood insurance study; FEMA, Federal Emergency Management Agency; ft, foot; USACE, U.S. Army Corps of Engineers; HEC–RAS, Hydrologic Engineering Centers–River Analysis System; NAVD 88, North American Vertical Datum of 1988; DS, downstream; US, upstream; Rt., Route; Rd., Road; Ave., Avenue; USGS, U.S. Geological Survey; MA, Massachusetts; St., Street; NGVD 29, National Geodetic Vertical Datum of 1929]

Description of location	FIS, town of Williamstown (FEMA, 1983b) and city of North Adams, Massachusetts (FEMA, 1981)	Lombard and Bent (2015a) USACE HEC–RAS hydraulic model	FIS, town of Williamstown (FEMA, 1983b) and city of North Adams (FEMA, 1981)	Lombard and Bent (2015a) USACE HEC–RAS hydraulic model	Difference between FIS and Lombard and Bent (2015a) USACE HEC–RAS hydraulic model water-surface elevation (ft)
	Location from Massachusetts-Vermont State border (ft)	Location from Massachusetts-Vermont State border (ft)	Water-surface elevation, converted to NAVD 88 (ft)[a]	Water-surface elevation, NAVD 88 (ft)	
DS from State Rt. 2, North Adams	37,450	37,108	643.9	651.1	7.2
US from State Rt. 2, North Adams	37,700	37,550	651.0	651.9	0.9
DS from railroad bridge, North Adams	38,700	38,212	658.2	658.6	0.4
US from railroad bridge, North Adams	38,800	38,624	659.5	662.0	2.5
US from Brown St., North Adams	43,400	42,461	679.2	681.3	2.1
DS from Brown St., North Adams	43,500	42,774	679.6	683.0	3.4
			Number of observations		26
			Minimum		-2.7
			Maximum		7.2
			Average		0.7
			Median		0.6

[a]The average conversion value from NGVD 29 to NAVD 88 for the FIS water-surface elevations was -0.52 ft. The conversion was done using the National Geodetic Service VERTCON orthometric height conversion program (Gilbert, 1999) at http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl.

The differences in water-surface elevations between the recent (2015–16) hydraulic studies and the FISs likely are because of (1) improved land elevation data from lidar data collected in 2012, (2) detailed surveying of hydraulic structures and cross sections throughout the river reaches in 2012–13 (reflecting structure and cross section changes during the past 30 to 35 years), (3) updated hydrology analyses (30–35 water years of additional peak flow data at streamgages), and (4) high-water marks from the 2011 tropical storm Irene flood being used for model calibration. These updated components used in the recent hydraulic models improved the simulated water-surface elevations for these river reaches. Additionally, the differences observed between the 1-percent AEP water-surface elevations for the recent studies and those in the FISs could be related to land-use changes—such as any increases in greater area of urban land uses because of increased medium- to high-density areas of residential housing, commercial and industrial development, and roads and highways in the river basins.

Summary and Conclusions

On August 28, 2011, intense rainfall of 3 to 10 inches that resulted from tropical storm Irene caused widespread flooding in western Massachusetts. August rainfall in western Massachusetts before tropical storm Irene had already saturated the ground, resulting in conditions prone to flooding. During a 9 to 18 hour period on August 28, 2011, the gage heights at all eight active U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins rose rapidly in response to the combination of saturated soils and intense rainfall. At Deerfield River near West Deerfield, Mass., streamgage (01170000), stage rose nearly 20 feet (ft) in less than 4 hours. On August 28, 2011, in the Deerfield and Hoosic River Basins in northwestern Massachusetts, new peaks of record were set at six of eight U.S. Geological Survey long-term streamgages with 46 to 100 years of record. Additionally, high-water marks were surveyed and indirect measurements of peak discharge were calculated at two discontinued streamgages in the Deerfield and Hoosic River Basins with 24 and 61 years of record, respectively. This data resulted in new historic peaks of record at the two discontinued streamgages from tropical storm Irene. In response to the tropical storm Irene flooding in western Massachusetts, a Presidential disaster declaration for Massachusetts was signed in September 2011. An interagency agreement between the Federal Emergency Management Agency and the U.S. Geological Survey was signed in April 2012 to update the hydrology and hydraulics of selected river reaches in the Deerfield and Hoosic River Basins in northwestern Massachusetts.

Peak flows that resulted from tropical storm Irene (August 28, 2011) were determined at the U.S. Geological Survey streamgages in the Deerfield and Hoosic River Basins by using stage-discharge rating curves and indirect computation methods. At the six streamgages in the Deerfield River Basin, peak flows from tropical storm Irene ranged from 1- to less than 0.2-percent annual exceedance probabilities (AEPs). At the four streamgages in the Hoosic River Basin, peak flows from Irene ranged from 5.4- to 0.4-percent AEPs. Generally, the AEPs were lowest at streamgages with river basins in the areas that had the higher rainfall amounts in northwestern Massachusetts.

The AEP discharges computed at streamgages for this study were compared with AEP discharges in the effective Federal Emergency Management Agency flood insurance studies (FISs) for communities in the study area, which were published in the late 1970s and early 1980s. Computed discharges for the 10-, 2-, 1-, and 0.2-percent AEPs at four streamgages (two on the main stem and two on tributaries to the Deerfield River) in the Deerfield River Basin, with 30 to 35 years of additional annual peak flow data, were generally higher than discharges in the FISs. The AEP discharges calculated for this study at two streamgages on the main stem of the Deerfield River ranged from about 3 percent lower to 14 percent higher than in the FISs. For the two streamgages on tributaries to the Deerfield River, estimated AEP discharges were considerably higher (from 27 to 89 percent) than in the FISs. For the four streamgages in the Hoosic River Basin, the 10-, 2-, 1-, and 0.2-percent AEP discharges estimated generally ranged from 33 percent lower to 5 percent higher than in the FISs.

The 1-percent AEP discharge water-surface elevations (nonregulatory) simulated from the hydraulic models for the Deerfield, Green, and North Rivers in the Deerfield River Basin and the Hoosic River in the Hoosic River Basin were compared with those in the FISs. The differences in the 1-percent AEP discharge water-surface elevations for this study to those in the FISs varied throughout the river reaches; however, the average water-surface elevations for this study were higher than those in the FISs. At the selected locations on the Deerfield River, the 1-percent AEP discharge water-surface elevations ranged from 2.0 ft lower to 7.3 ft higher than water-surface elevations in the FISs, with average and median differences in water-surface elevations of 2.2 and 1.5 ft higher, respectively. At the selected locations on the Green River, the 1-percent AEP discharge water-surface elevations ranged from 6.1 ft lower to 6.1 ft higher than in the FIS, with average and median differences in water-surface elevations of 2.3 and 2.4 ft higher, respectively. At the selected locations on the North River, the 1-percent AEP discharge water-surface elevations ranged from 7.6 ft lower to 3.7 ft higher than in the FIS, with average and median differences in water-surface elevations of 0.3 and 1.7 ft higher, respectively. At the selected locations on the Hoosic River, the 1-percent AEP discharge water-surface elevations ranged from 2.7 ft lower to 7.2 ft higher than in the FISs, with average and median differences in water-surface elevations of 0.7 and 0.6 ft higher, respectively. The differences in water-surface elevations between the recent (2015–16) hydraulic studies and the FISs likely are because of (1) improved land elevation data from light detection and ranging (lidar) data collected in 2012, (2) detailed surveying of hydraulic structures and cross sections throughout the river reaches in 2012–13 (reflecting structure and cross section changes during the last 30–35 years), (3) updated hydrology analyses (30–35 water years of additional peak flow data at streamgages), and (4) high-water marks from the 2011 tropical storm Irene flood being used for model calibration. Additionally, the water-surface elevation differences could be related to land-use changes—such as any increases in area of urban land uses because of increased medium- to high-density areas of residential housing, commercial and industrial development, and roads and highways in the river basins.

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